Intraoperative tools for cerebral bypass surgery

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Abstract. We discuss the role of the currently available intra-operative tools in cerebral bypass surgery. Each has in fact its own advantages and limitations that the surgeon needs to understand. Most of these intraoperative devices are complementary and depending on the bypass type and on the underlying disease to be treated, the most adapted tool needs to be selected for optimal decision making during bypass surgery.

Cerebral bypass surgery is classified according to the role of the bypass in flow-preservation and flow-augmentation procedures. [7] The role of a flow-preservation bypass is to replace the blood flow provided by a major intracranial vessel, the occlusion of which is necessary for treating an underlying disease (such as complex aneurysms). The role of a flow-augmentation bypass is to restore flow to hypoperfused brain territories (in patients with steno-occlusive diseases).[7, 10, 12]

Flow-preservation bypass plays an important role for managing complex intracranial aneurysms not amenable to selective clipping or endovascular treatment. Flow-preservation bypass is instead nowadays very rarely indicated for managing tumors involving major cerebral arteries: in these cases the trend has evolved in favour of partial resection and radiotherapy. [7] For what concerns flow-augmentation bypass, it is currently recommended for Moyamoya patients with ischemic or hemorrhagic symptoms and compromised hemodynamics. Bypass is currently not recommended for patients with recently symptomatic carotid artery occlusion and failure of cerebral hemodynamics, but may be considered for patients with hemodynamic failure and recurrent symptoms despite optimal medical treatment.[7]
Cerebral bypass is a niche procedure that should be performed by dedicated cerebrovascular surgeons. When performing a bypass operation, the surgeon should be able to:

1. map and dissect high quality donor vessel
2. identify the correct recipient vessel
3. verify the patency of the anastomosis
4. verify the appropriateness of the direction of the flow in the bypass and in the recipient artery
5. quantify the flow in the bypass, allowing to predict bypass function (for flow-augmentation bypass) and to verify that the bypass match the flow demand (for flow-preservation bypass)

For this purpose, the surgeon can implement the use of one or more of the following intra-operative tools: digital subtraction angiography (DSA), Doppler ultrasonography, microscope-integrated near-infrared Indocyanine green videoangiography (ICG-VA), dual image video-angiography (DIVA), fluorescein-videoangiography (f-VA), quantitative flowmetry.

Intraoperative DSA is the gold-standard technique for the evaluation of the patency of a graft/bypass. DSA allows in fact verifying the patency of the anastomosis and the correctness of the direction of the flow in the bypass and in the recipient artery. It gives dynamic information on bypass function such as the extent of intracranial filling. DSA can also reveal the fate of a complex aneurysm following bypass surgery and/or trapping strategies (aneurysmal thrombosis, residual filling).[23] Drawbacks are represented by its invasiveness, high costs, necessity of ionizing radiation, prolonged operative time (15-60 minutes). [14, 22, 23, 25]

Doppler ultrasonography can detect blood flow velocities non-invasively and allows verifying the patency of the anastomosis and the correctness of the flow direction.[5, 23] Furthermore, it is useful for mapping a scalp donor artery (such as the superficial temporal artery – STA – or the occipital artery). [8] It can be difficult to place the probe on the target vessel in a deep surgical field. Furthermore, even if the target vessel can be touched with the probe, it may detect flow from

nearby vessels: in fact, the continuous Doppler wave method detects blood flow in a relative wide region.[22]

Microscope-integrated near-infrared indocyanine green videoangiography (ICG-VA) is an easy-to-use, fast, low-cost and non-invasive technique introduced in neurosurgery by Raabe et al in 2003 for intraoperative observation and documentation of blood flow of large and small vessels. Its image quality and spatial and temporal resolution allow real-time assessment of the cerebral circulation and distinct evaluation of arterial, capillary, and venous phases.[9, 23] ICG-VA can be performed using a commercially available surgical microscopes. Indocyanine green is a near infrared diagnostic dye with an absorption and emission peaks of 805 and 835 nm, respectively. Its half-life is about 3–4 min. [21] A standard dose of 12.5 mg or 25 mg of ICG is dissolved in 5 mL of water and injected into a vein as a bolus. Fluorescence is observable with a latency of 4 seconds, after injection in central veins. Some seconds more (6-8 seconds) after injection into a peripheral vein. ICG-VA videos can be analysed on video screen and recorded for further analysis. [8] ICG-VA has become a routine adjunct to surgery in almost all the vascular neurosurgery procedures including bypass surgery.[21] ICG-VA can be repeated as many times as needed within the daily dose limit of ICG (5 mg/kg): one has however to wait at least 10 minutes between intravenous ICG injections. However the quality of image and analysis progressively declines with every administration.[17] Disadvantage of ICG-VA are: the limited visualization restricted to the visible operating field; [20] the poor image quality in deep operative fields (for instance in surgery of anterior communicating complex); the inability to observe structures (brain, nerve) other than NIR (near infrared) fluorescence images of vessels: the background is in fact black [13, 16]. Finally, fluorescence run cannot be observed in real-time through the operating oculars. The surgeon needs to follow the angiography on an adjacent monitor. Only the replay-function allows visualization through the oculars (but not real-time).[13, 17, 20]

In bypass surgery, ICG-VA allows assessment of patency of the anastomosis, as well as of the donor and recipient vessel. ICG-VA provides a good black-and-white image quality, enabling the surgeon to quickly estimate early bypass occlusion as well as occlusion site. ICG-VA also allows visualization of the direction of the flow, providing a reliable estimation of flow velocity during first pass. [20]

ICG-VA is also helpful for mapping the donor artery (STA) in STA-MCA bypass surgery, mostly when the frontal branch of the STA needs to be dissected from the underside of the scalp flap. This technique is based on the analysis of the difference in time of filling of scalp vessels illuminated via ICG-VA from the underside of a scalp flap.[8]

Techniques employing the use of ICG-VA have been also developed in order to eliminate the risk of erroneous revascularization in flow-preservation bypass performed for managing complex aneurysm of the middle cerebral artery. [6, 9, 11, 14, 19] These techniques are based on the analysis of the difference in the direction and in the time of filling of M4 cortical arteries at the

craniotomy site. In flow-preservation bypass a key element is in fact the correct target of the recipient artery. The possibility to select a superficial recipient (M4) artery makes a bypass easier and safer.[9, 11]
The availability of FLOW 800 (a microscope-integrated software) allows instant color-coded visualization and analysis of the temporal distribution dynamics of the ICG. Flow 800 cannot assess continuously the flow in real-time. FLOW 800 may detect procedure-related hemodynamic changes within the microcirculation and macrocirculation but should not be used as a stand-alone tool for quantitative flow assessment.[18]

The dual-image video angiography (DIVA) is a new intraoperative imaging system for assessment of blood flow within cerebral vessel. [20] The DIVA system can be mounted on an intraoperative microscope. DIVA requires the same conventional ICG injection (bolus of 12.5 mg) without any need for additional injections. DIVA allows simultaneously visualization of both light and NIR fluorescence images of ICG-VA.[20] Although image contrast between vascular structures and background is higher with standard black-and-white ICG-VA, DIVA highlights vessels and provides simultaneous visualization of the surrounding structures including brain, nerves, etc. The anatomic and functional picture is immediately clear.[13, 20] DIVA seems to be superior to ICG-VA in showing the depth of the field and can be therefore useful in case of deep and narrow surgical corridor, with vascular structures located at different depths. [13, 20] As limitation, DIVA allows visualization only of the structured exposed within the operative field (same limitation of ICG-VA). Fluorescence run cannot be observed in real-time through the operating oculars: as with ICG-VA, the surgeon needs to follow the angiography on a monitor. DIVA has been further implemented in cerebral bypass surgery allowing [13, 20]: 1) verification of patency of the anastomosis, of the donor and of the recipient vessel; 2) visualization of the direction of the flow, providing a reliable estimation of flow velocity during first pass. [20] DIVA has the potential to become a widely used intraoperative tool to check patency of intracranial vessels. Currently DIVA should be considered a complementary tool and not a replacement of standard ICG-VA.[13]

The Fluorescein videoangiography (f-VA) technique reported by Narducci [17] et al also enables evaluation of vascular flow and has been proposed as intra-operative imaging system in cerebral bypass surgery.[15, 24] The fluorescence filter module (YELLOW 560) for imaging fluorescein fluorescence is integrated in the intraoperative microscope. The same microscope can also be equipped with integrated ICG-VA and FLOW-800 modules. Matano et al [16] reported on the central intravenous administration of a 250 mg bolus dose of fluorescein, and Narducci et al [17] on the administration of 500 mg through a peripheral vein. As ICG, sodium fluorescein is easy to administer, inexpensive, and require no extra equipment or personnel. The area of interest is illuminated with the microscope set to YELLOW 560 module. Fluorescence is observable with a

latency between 15 and 20 seconds after administration: arterial, capillary and venous phases can be clearly defined. The surgeon visualizes the angiography directly through the microscope oculars, without the necessity to interrupt the procedure to look at an adjacent monitor. [16, 17] Manipulation of the vessels during videoangiography is possible. The angiography is also observable through the HD monitor of the microscope and operative videos can be recorded for further analysis. f-VA technique shows good sensitivity in verification of bypass patency, providing good visualization of flow, flow direction within donor and recipient arteries, filling of cortical vessels. It is possible to safely repeat administration, since the dose of sodium fluorescein commonly used in other fields (i.e. glioma surgery) is up to 20 mg/kg [1, 17]. If necessary, f-VA can be repeated after 20-25 minutes, following clearance of most of the fluorescent signal: this is something more than the 10-15 minutes needed to repeat an ICG run [16, 17]. However, some vessel stain can be observed after intravascular clearance, making interpretation of imaging less reasonable. [16, 17]

As reported by Narducci[17] et al, in comparison to ICG-VA, f-VA has the following advantages: 1) allows visualization through the microscope oculars; 2) allows visualization of the surrounding tissue; 3) allows visualization of a higher number of cortical vessels (providing a better idea of cortical perfusion). The first two characteristics may be useful in case of deep located anastomosis, where manipulation of vascular and parenchymal structures may be needed.

The main limitations, in comparison with ICG-VA, are: 1) the lower-sensitivity in flow-velocity assessment during first pass; 2) the absence of an integrated software for analysis of the temporal distribution of the dye (i.e. FLOW 800); 3) the prolonged clearance time of the fluorescein, in comparison with ICG. [16]

All the intra-operative tools above described do not allow however quantification of the flow (in ml/min). Direct intraoperative flow measurements can be made with the use of a microvascular ultrasonic flow probe on donor and recipient vessels. [3] The flow in ml/min appears as a waveform and as a digital display on the detection unit and is indicated as positive or negative depending on the direction of flow relative to the orientation of the probe. [2-4] It allows quantification of the flow and indirect information on the patency of the anastomosis (by measuring the donor and the recipient distally and proximally to the anastomosis). It can, however, be difficult to place the probe on the target vessel in a deep surgical field. Flowmetry also allows measuring the flow capacity of a donor vessel by calculation the cut flow. [2] When performing a flow-preservation bypass, matching the bypass flow to the demand of the brain territory perfused by the sacrificed artery is the key-element. After the anastomosis, intraoperative quantitative flow measurements are essential to confirm that the capacity of the bypass matches the flow demand of the vascular territory. [2] In flow-augmentation bypass, calculation of the Cut Flow Index (CFI) allows to predict bypass function and success. CFI is defined as the ratio bypass flow / cut flow. A CFI of 1.0

indicates a highly successful bypass. [2-4]

Among all the intra-operative tools herein described, each has its own advantages and limitations that the surgeon needs to understand. Most of these intraoperative devices are complementary and depending on the bypass type and on the underlying disease to be treated, the most adapted tool needs to be selected for optimal decision making during bypass surgery.

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